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Bulletin No. 11.

UNION OF SOUTH AFRICA

DEPARTMENT OF MINES

VERMICULITE DEPOSITS

IN THE

PALABOROA AREA, N.E. TRANSVAAL

BY

C. M. SCHWELLNUS, B.Sc.

PUBLICATION OF THE GEOLOGICAL SURVEY DIVISION

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0
100
200
300 MILES.

Fig. 1.

The Vermiculite Deposits in the Palaboroa Area, N.E. Transvaal.

ABSTRACT.

Vermiculite deposits occur in pyroxenites and serpentinous rocks which occupy an area of some six to seven square miles near the confluence of the Selati and the Olifants rivers in the Lowveld region of the N.E. Transvaal.

The quality of vermiculite in general is good and the available quantities are very large. The vermiculite was tested in the Minerals Research Laboratory, Johannesburg, for its commercial properties. The results, which are encouraging, are incorporated in an appendix at the end of this bulletin.

Judging from the grade, quantities and other economic aspects of this occurrence it is likely that a lucrative vermiculite industry could be established at Palaboroa.

I.—INTRODUCTION.

During the months of May and June, 1936, the writer was engaged in a geological survey of the area from the Olifants river northwards along the western boundary of the Kruger National Park. A geological map of that portion of the area dealt with here appears on page 10.

This bulletin is intended to bring to light and to put on record the results of the most recent investigation of the mineral vermiculite which has hitherto not been described from that part of the country.

The appendix was prepared by Mr. J. E. Laschinger. I should like to record my appreciation of the results so generously provided by him through the good offices of Professor G. H. Stanley, Director of the Minerals Research Laboratory, Johannesburg.

The writer's thanks are due to Mr. and Mrs. Max Ruh, who occupy the last European outpost in this part of the Transvaal. The writer greatly appreciated their kind hospitality and the assistance, in this comparatively unknown bush-covered country, always readily given by Mr. Ruh.

II.—PHYSICAL FEATURES.

The area forms part of the typical Low country Bushveld and its average height above sea level is approximately 1,200 feet. The highest peak is the N.G.H. beacon situated on the hill Skotini on the farm Schiettocht No. 197. This point is 1,870 feet above sea level. Loole Kop is 1,750 feet, and the bed of the Selati river just below April Kop is about 1,100 feet above sea level.

The monotony of the typical Lowveld is here broken by a cluster of closely spaced rocky kopjes which stand out prominently in the otherwise flat bushy country. Loole Kop, approximately in the centre of these kopjes, is a large rounded elevation, the top of which bears several prominent outcrops.

The Olifants and Selati rivers are the only courses which maintain a constant flow throughout the dry season ; in very dry years even the Selati river has no flowing water. Away from the larger rivers water is rather scarce. Wells dug in the banks or in dry sandy river courses generally yield a good supply of fresh water. A borehole on which the Palaboroa pump is erected on the farm Schiettocht No. 197 yields a constant supply of water. The water is, however, brackish.

Rainfall in this area is very sporadic and small showers can be expected almost any month of the year. The best rains, however, fall during the mid-summer months. The annual rainfall since 1924 averages about 17 inches.

Although it may become exceptionally hot in the summer months the temperature is as a rule not unbearable ; but malaria is endemic and precautions against it are essential.

III.—GENERAL GEOLOGY.

The geology of the area will be described briefly. For more detailed geological descriptions about this area the reader is referred to publications by Hall, (1) Shand, (2) and du Toit (3).

TABLE OF FORMATIONS.

Surface limestone	Recent.
Dolerite dykes	Karoo (?).
Vermiculite deposition	Old granite and related intrusions.
Apatite deposition	
Syenite intrusions (plugs and dykes)	
Old granite and related facies	
Crystalline limestones	Swaziland System.
Pyroxenite	
Ancient schists	

The area is underlain principally by granites and schistose rocks of various kinds. Pyroxenites, covering some six to seven square miles are, however, the most important formation. Both the apatite and vermiculite deposits of any size are confined to this rock.

(1) A. L. Hall : "The Geology of the Murchison Range and District." Mem. geol. Surv. S. Afr. No. 6, 1912.

(2) S. J. Shand : "The Granite-Syenite-Limestone Complex of Palabora, Eastern Transvaal." Trans. geol. Soc. S. Afr. Vol. XXXIV, 1931, pp. 81–104.

(3) A. L. du Toit : "The Genesis of the Pyroxenite-Apatite Rocks of Palabora, Eastern Transvaal." Trans. geol. Soc. S. Afr. Vol. XXXIV, 1931, pp. 107–127.

The ancient schistose rocks vary from place to place and comprise amphibolite schists, micaceous schists, phyllites, garnetiferous schists, and highly sheared epidotised quartzites. The strike of these schists ranges from N.E.–S.W. to E.–W. and their dip is mostly vertical.

Crystalline limestones form the conspicuous Loole Kop which stands out some 400 to 500 feet above the general level of the surrounding country. The limestone shows a mineral banding which seems to denote original bedding planes. This banding is parallel to the major direction of gneissic foliation of the surrounding Older granites. Magnetite and apatite are abundant in this limestone. Small specks of chalcopyrite and bornite, together with their weathering products malachite and azurite, are very frequently seen in the crystalline limestones. At several places on Loole Kop muscovite has been found and, to a much smaller extent, phlogopite. In one place the phlogopite has been partially altered to vermiculite.

Rocks shown as pyroxenites on the accompanying geological map do not comprise pyroxenites alone but also serpentines and actinolitic rocks which seem to be closely related to the pyroxenites and occur sparingly within the latter. The pyroxenite of this area is totally different to those of the Bushveld Complex, Insizwa, and other areas where they have been shown to be products of magmatic differentiation. The Palaboroa pyroxenite is a greenish rock composed predominantly of a diopsidic pyroxene. Interstitial felspar is frequently developed near the contacts of this rock with the surrounding syenites. Evidence leading to the conclusion that the syenite is intrusive into the pyroxenite has also been found. No muscovite occurs in the pyroxenites surrounding Loole Kop, but vermiculite and phlogopite are present. Apatite is often closely associated with the vermiculite deposits.

The crystalline limestones, ancient schists, and also the pyroxenites, probably represent xenoliths of varying rock types belonging to the Swaziland system.

GEOLOGICAL MAP OF THE AREA AROUND LOOLE KOP.
C. M. SCHWELLNUS, B.Sc.

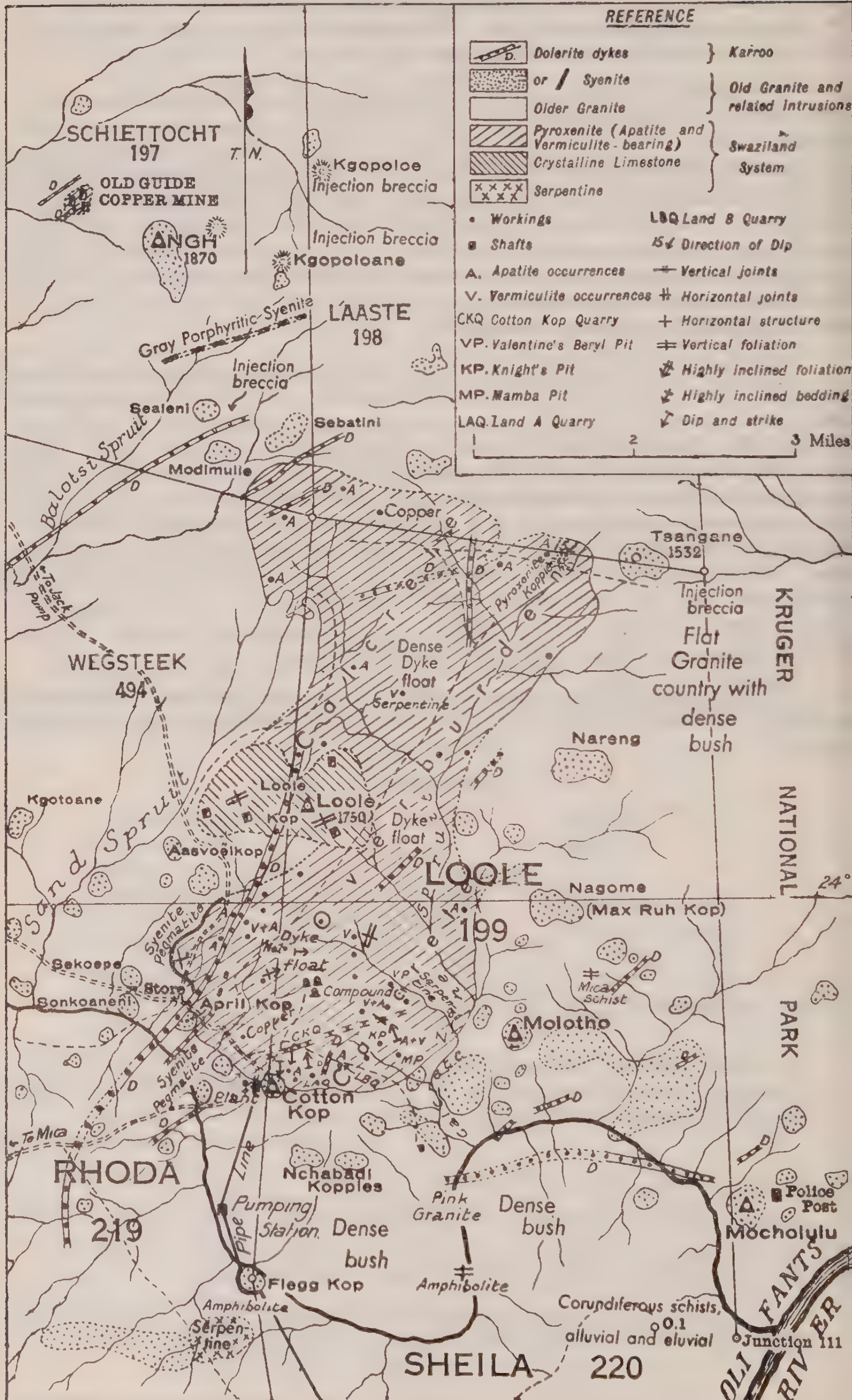

FIG. 2.

By far the larger part of the area illustrated in figure 2 is occupied by the Older granite. Typical gneissic granite is exposed at numerous localities. The "Younger granite" as indicated by Hall (1) only occupies a very small portion of this area. This rock is distinguished from the Older granite by its generally comparatively fresh appearance, pinkish colour, absence of gneissic structure and tendency to porphyritic texture. It occurs as small localised intrusions in the Older granite. Owing to this, and because it is not certain at present whether the so-called "Younger granite" is definitely later in age or merely represents a later surge from the same magma reservoir from which the Older granite issued, all the granite rocks are inserted in the accompanying geological map as Older granite. The general tendency for this "Younger granite" is to trend in a roughly N.E.—S.W. direction in conformity with the general direction of gneissic foliation in the Older granite.

All around Loole Kop there are a number of rocky peaks which rise well above the general level of the surrounding flat country. Without exception these peaks have been found to be composed of syenitic rocks. Within the area, at several sites, injection breccias occur in the immediate vicinity of syenitic intrusions. Outside the area delineated by figure 2 such injection breccias are in contact and encircle syenite plugs in the Older granite. Syenite dykes occur at various localities; they are mostly in the vicinity of syenite plugs. The dykes have nowhere been found to cut across the plugs.

Numerous basic dykes of doleritic composition strike in a roughly N.E.–S.W. direction and have been found to cut across all the previously described formations.

A thick overburden of calcrete covers the pyroxenite almost everywhere. The confinement of the calcrete to the pyroxenite is so striking that prospecting to any extent was only carried out where this rock existed. The presence of this extensive calcrete cover is unfortunate in that it renders the location and prospecting of the underlying deposits very difficult. At its thickest, the calcrete overburden was found to be well over twelve feet in some of the abandoned workings.

IV.—THE VERMICULITE DEPOSITS.

Vermiculite is genetically related to apatite in the Palaboroa deposits and these two minerals are found in close association in most of the occurences. In some cases there are deposits of pure vermiculite; in other instances again massive apatite unaccompanied by vermiculite is found. In most of the deposits, however, small negligible quantities of vermiculite either fringe or cut across lenses or pockets of massive apatite. In some occurrences where vermiculite predominates, occasional small flat interlaminated apatite and pyroxene appear. In other instances where the apatite is present in small quantities in vermiculite-rich deposits it forms large well-formed crystals with rounded, pitted and glazed surfaces.

The vermiculite of this area seems to have been formed from phlogopitic mica which it closely resembles. Its cleavage laminae are usually soft, pliable and inelastic. It has a yellowish-brown colour and bronze-like lustre. The chief characteristic feature of this mineral is that when heated it loses water and gradually swells up or exfoliates to form a bulky mass many times its original size. Even the heat of a candle flame is sufficient to cause appreciable exfoliation.

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(1) A. L. Hall: "The Geology of the Murchison Range and District." Mem. geol. Surv. S. Afr. No. 6, 1912, pp. 105–130.

Deposits of vermiculite are here confined to the pyroxenites and related rocks, and constitute the largest known deposits of this mineral in the Union. The pyroxenite area covering some six to seven square miles is studded with pits and quarries originally put down in search of apatite. Vermiculite has been exposed in many of them but has received very little attention by prospectors until recently. The opening up of vermiculite is thus largely to be attributed to its frequent intimate association with the apatite upon which extensive prospecting has been carried out.

Vermiculite deposits occur as masses and lenticular bodies of irregular shape, and form bunches or pockets, discontinuous streaks and disseminations. During the discussion of some of the individual occurrences the above modes of occurrence will become apparent.

DESCRIPTION OF THE DEPOSITS.

Owing to the similarity of the deposits only the most important ones will be described in detail.

Valentine's Beryl Pit. (V.P.)*—Situated one mile to the south of the Loole trigonometrical beacon on the farm Loole No. 1991, this working is on the site where apatite was first found in any appreciable quantity. The discovery induced further prospecting which soon led to the discovery of other more extensive bodies of apatite in other parts of the pyroxenite area.

In a pit 5 by 10 feet across and 25 to 30 feet deep, vermiculite borders the larger part of the opening. Pyroxene crystals occur in the vermiculite as isolated large well-formed individuals up to one foot across. The apatite is of the apple-green highly crystalline variety and occurs either in a streaky manner or as pockety aggregates of small dimensions. Some vermiculite flakes have been found to measure up to nine inches across whereas the flaky masses in places measure over six inches in thickness. There is no tendency towards a parallel arrangement of the vermiculite flakes which are irregularly disposed in this working. The vermiculite, apatite and pyroxene occur in the proportion 65 per cent. : 30 per cent. : 5 per cent.

The country rock of this apatite-vermiculite deposit is not exposed in the pit, but about five yards to the east of the working a massive serpentinous rock protrudes from the soil mixed with calcrete which forms a thin overburden in this part.

It is to be remembered that at the time of the opening up of this pit all prospecting was concentrated on apatite and the value of the accompanying vermiculite was not realised.

Various other workings in the immediate vicinity of this pit indicate the presence of apatite and vermiculite in greatly varying proportions. The vermiculite seems to occur everywhere in larger quantities than the apatite.

Tests on vermiculite from the deepest portion of Valentine's Beryl Pit by Mr. F. C. Partridge proved it to be comparable in exfoliating properties to that marketed overseas (see page 18). The Minerals Research Laboratory states that the material from this pit submitted to them " expands fairly well, yielding material of good silver-white to faintly brown colour " (see page 24).

* The abbreviations in brackets refer to those on the geological map on page 10 on which they indicate the relative positions of the individual workings.

The Mamba Pit (M.P.)—Prospecting directed towards a lenticular body of massive apatite situated in a finegrained, almost granular mass of vermiculite admixed with apatite exposed large quantities of vermiculite. It is said that between 80 and 90 tons of high-grade apatite were mined from this working, which is at least 25 ft. long, 15 ft. wide and about 15 ft. deep. To-day hardly any apatite is left in the pit, the sides of which are wholly of vermiculite. On account of the calcrete overburden the limit of the extent of this material beyond the pit could not be established.

Vermiculite from this locality tested by Mr. F. C. Partridge and the Minerals Research Laboratory proved to be good as far as exfoliation is concerned but it contains minute rounded blades of a hard mineral, probably apatite, and some pyroxene. Some suitable mechanical process may however be found to separate the vermiculite from these impurities which may be detrimental.

SECTION THROUGH APATITE DEPOSIT IN THE LAND A QUARRY.

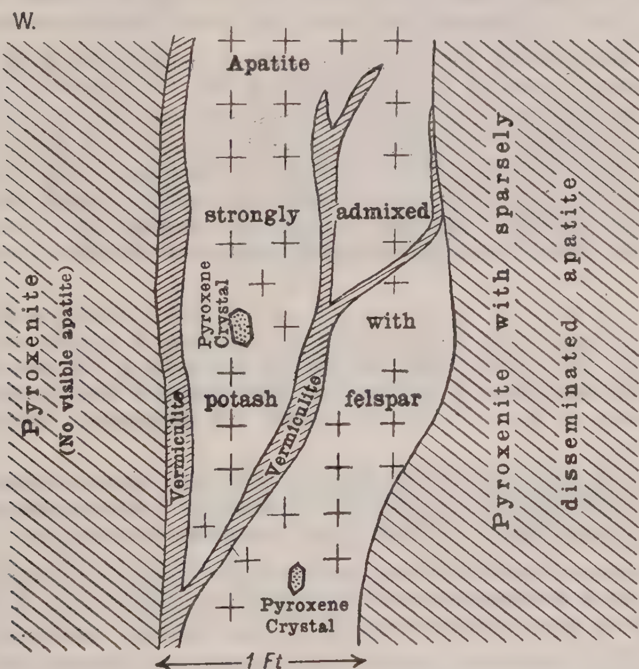

FIG. 3.

Land A Quarry (L.A.Q.)—Although the vermiculite exposed in this quarry does not occur in any appreciable quantity, its mode of occurrence and relation to the apatite deposits are clearly shown on a small scale. The country rock here is a pyroxenite typical of that forming the rest of the pyroxenite area.

On the northern face of one of the numerous workings at this locality an apatite body about twelve to fifteen inches wide is exposed (see figure 3). Pink felspar, forming about 5 per cent. of the mass, is disseminated through the apatite. The deposit is everywhere sharply separated from the country rock, pyroxenite, which shows a sparse dissemination of apatite on the eastern flanks of the apatite body, while the western side is macroscopically devoid of apatite. A stringer of vermiculite one inch wide is visible at the bottom

of the working where it splits into two narrow veinlets, one extending along the contact of the apatite with the pyroxenite, while the other cuts obliquely across the apatite and felspar. This latter stringer branches at intervals and one such offshoot abuts against the apatite and pyroxenite contact on the eastern side of the deposit; from here it follows the contact between the apatite and the country rock. Occasional large and well-formed pyroxene crystals are embedded in the apatite. A few isolated flakes of vermiculite have been observed in the pyroxenite adjoining the vermiculite stringer.

In this quarry as well as in other localities the pyroxenite frequently bears isolated masses or rounded pockets of vermiculite. These vary considerably in size from place to place. Some measured over four feet in diameter while others are merely represented by small globular masses of less than an inch across. In the country rock finely disseminated vermiculite occasionally accompanies such local enrichments.

Discontinuous streaks and bands of vermiculite have also been found but are of very limited extent and seem not worth mining.

The Wegsteek No. 494 *Occurrence.*—About one mile S.S.W. of the Loole trigonometrical beacon on the farm Wegsteek No. 494 numerous pits disclose the intimate association of vermiculite deposits with apatite. The apatite recovered from these workings formed irregular pockets and lenticular masses in the vermiculite. Almost all the available apatite has been removed. Unfortunately the vermiculite is everywhere thoroughly admixed with calcrete. This apparently is only due to the fact that the workings are all very shallow. In depth the calcrete should become an insignificant factor or be altogether absent.

In a pit 50 feet long, 12 feet wide, and 10 feet deep all the faces consist largely of vermiculite in which subordinate amounts of apatite and pyroxene are present. The apatite forms less than 5 per cent. of the material visible on the walls, while there is perhaps even less pyroxene than apatite. In the upper portions of the walls there is veined and impregnated calcrete in the vermiculite.

Various other pits in this vicinity show the intimate association of vermiculite with apatite and pyroxene. The ore is in all respects very similar to, but very much lighter in colour than, that of the Mamba pit.

The country rock of these deposits is not exposed anywhere in these workings but a few fragments of serpentinous rock have been found on the surface. They may represent remnants of the weathered country rock.

The No. 1 *Working.* (*No.* 1.)—The pits known as No. 1 Working are situated about three quarter mile due south of the Loole trigonometrical beacon. The country rock is pyroxenite, and vermiculite accompanies the apatite in varying amounts. The larger deposits all strike in a roughly north-southerly direction, and are either vertical or dip steeply in an easterly direction.

In the western most pit of these workings apatite and vermiculite are intimately associated. A deposit about twelve feet wide carries pyroxene in appreciable proportions in addition to vermiculite and apatite (see figure 4). Apatite carrying nearly 50 per cent. of diopside forms the western part of the deposit. There are a few irregular and isolated patches of vermiculite in this matrix of apatite and diopside. Near the centre of the deposit a narrow irregular vein-like body of apatite appears. The eastern part of the deposit over a width of about seven feet is rich in vermiculite. Numerous almost vertical discontinuous stingers and small pockets of apatite occur in this vermiculite-

rich portion. Occasional flat interbladed crystals of pyroxene have been observed. Where an isolated fragment of pyroxenite is embedded in the vermiculite the flakes of the latter mineral are very much larger immediately around the pyroxenite. It is possible that the vermiculite was formed at the expense of, or by reaction with, the pyroxenite.

The Northern Face of the No. 1 Working, Palaboroa.

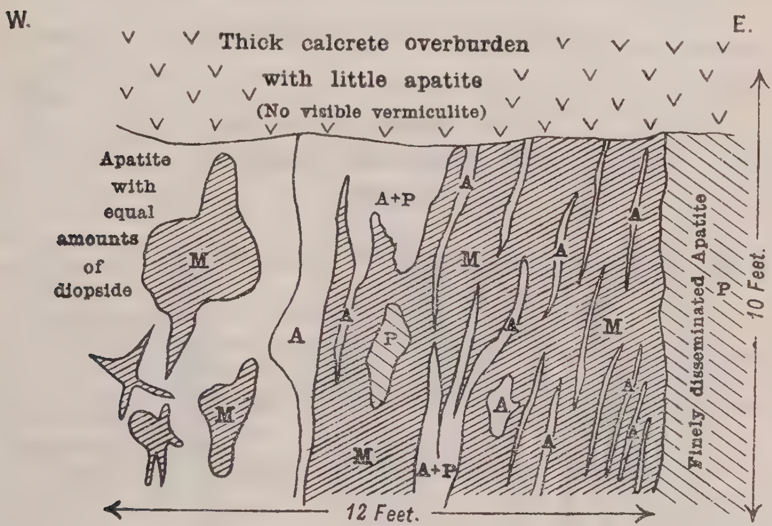

Fig. 4.

A = pure apatite veins, lenses and pockets in vermiculite.
P = pyroxenite with sparse disseminations of apatite.
A and P = Apatite with subordinate amounts of pyroxene.
M = Vermiculite.

In a small pit to the south-east of the main working two closely-spaced vein-like bodies of apatite and vermiculite occur in pyroxenite which displays well-defined jointing (see fig. 5). The overburden of calcrete at this site is thirteen feet thick. Disseminations and fragments of apatite are found in the surface limestone immediately above the deposits, but a few feet away laterally the apatite is absent. The vermiculite could not be found in the calcrete and does not seem to be preserved as a marker in the calcrete to the same extent as apatite. The northerly apatite vein is two feet wide at the bottom of the pit. About four feet higher up the body splits into three separate branches each about six inches wide, which taper to narrow stringers and eventually disappear against the calcrete. This apatite body is fringed on one side by a selvage of vermiculite one to two inches wide, which is very fine-grained and bears a fair amount of apatite. About three feet to the south of this deposit there is another one. It is about two inches wide at the bottom and suddenly swells to a width of about two feet and continues without change to the surface of the pyroxenite. Like the other vein, this one is also bordered on one side by a narrow zone of vermiculite.

Besides these two deposits vermiculite is very scarce in the pits constituting the No. 1 Working. There seems to be a general tendency for the vermiculite to decrease considerably in the pyroxenite and it is in many cases altogether absent when compared with the larger deposits which mostly seem to occur within or near serpentinous rocks.

About one mile N.N.E. of Loole Kop on the farm Loole No. 199 prospecting for vermiculite has recently been started. In places large flakes protruded from the soil, and the calcrete on this part of the pyroxenite showed vermiculite embedded in it at places. Several pits disclose vermiculite bodies which are over ten feet wide. The country rock is here a reddish-brown weathered serpentine. The pits as well as the surface indications seem to be aligned in a N.N.E.–S.S.W. direction and occur over a strike of at least 600 yards.

Apatite-Vermiculite Deposit in a Pit to the S.E. of No. 1 Working.

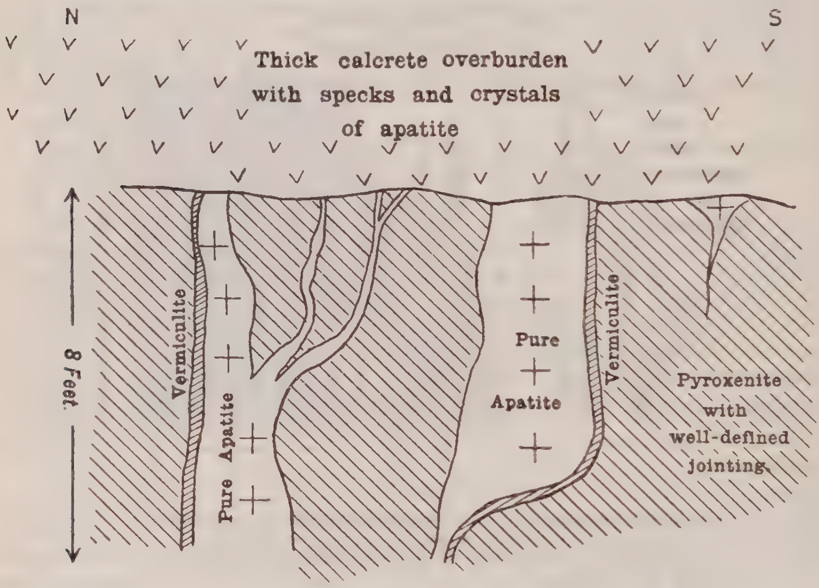

Fig. 5.

The vermiculite on the whole is very clean and occurs as large platy aggregates. The weathered material on the surface is of dull yellowish colour and does not exfoliate as well as the lustrous golden-yellow vermiculite proper found some ten to twelve feet down in the pits. Some of the material found in these pits exhibits a dark-brown core fringed by yellowish vermiculite. The inner material is slightly flexible and does not exfoliate as well as the surrounding vermiculite. Such material will have to be discarded during mining and can be sorted out by hand-picking.

It is still too early to estimate the reserves at this locality, but there seems to be little doubt that they must be extensive.

S.S.E. of Loole Kop, about one mile from the beacon on this hill, numerous pits have been sunk in the search for apatite. Some pits are in pure vermiculite deposits while others are in bodies where apatite and vermiculite were intimately associated. In all the pits the vermiculite occurs in quantities greatly exceeding that of the already extracted apatite. Some of the material does not expand well and occurs in the form of unaltered golden-brown phlogopitic mica. By handsorting it should be possible to sort out this material which is of no use for the purpose to which vermiculite is applied.

Surface limestone conceals all evidence of the extent of the vermiculite deposits beyond the limit of the individual pits. Hence no estimate of the quantities available can be given. The irregular pockety nature of these deposits is well exhibited in a few of the pits.

It is highly desirable that further samples from the above as well as other localities should be tested, so as to obviate mining material that is commercially useless.

THE ORIGIN OF VERMICULITE.

Evidence relative to the origin of vermiculite will not be given fully in this report. The conclusions arrived at are briefly the following.

The apatite and the vermiculite owe their origin to the granites or syenites surrounding the pyroxenites. The pyroxenite seems to occur in the form of a large xenolith. Most of the field evidence leads to the conclusion that the syenitic rocks formed the source of the ores. There also seems no doubt that the apatite and vermiculite are genetically related in the Palaboroa deposits.

Syenitic magmas are usually considered to carry much volatile matter which gives rise to mineral deposits of apatite, fluorite, etc. The presence of apatite deposits at Palaboroa has been known for many years, and the vermiculite probably also owes its formation to the fugitive constituents derived from the syenites.

Volatiles containing phosphorous, fluorine, chlorine and water besides other constituents permeated the pyroxenites which seemed to have been particularly amenable as a venue for the deposition of apatite and vermiculite. Hence the concentration of apatite and vermiculite in the form of streaks, pockets, lenticular bodies and disseminations took place in the pyroxenite mass. The phosphorus, chlorine and fluorine reacted with the available calcium to form apatite. The crystallisation of the apatite would naturally result in the concentration of water vapour in the remaining volatile constituents which did not participate in the formation of apatite. These remaining volatiles, it would appear, subsequently formed the phlogopite mica by reaction with the available magnesium in the country rock.

Field evidence as well as chemical analyses support the view that the vermiculite has been formed from phlogopitic mica. Whether the vermiculite is a weathered product of phlogopite or a hydrothermally altered product therefrom is uncertain. This would naturally affect the depth to which vermiculite extends and is therefore of great importance.

It is worthy of note to mention that the largest development of vermiculite is in or near outcrops of serpentinous rocks where the available magnesium would naturally be more than in the pyroxenite.

V.—ECONOMIC CONSIDERATIONS.

For further details regarding the commercial properties and other economic aspects of the vermiculite the reader is referred to the Appendix at the end of this bulletin.

(*a*) Grade.

Vermiculite occurs in flaky aggregates in which the individual flakes vary considerably in size from place to place. Three samples of material were

submitted to the Geological Survey Laboratory for preliminary investigation and Mr. F. C. Partridge, Senior Mineralogist, reported on them as follows :—

> "The material submitted from Palaboroa varies to some extent, but most of the samples seem to be of reasonably good quality. The best vermiculite so far examined came from Valentine's Pit and tests on this material indicate it to be comparable in exfoliating properties to that marketed overseas. It contains no detrimental impurities in so far as the hand specimens are concerned. It has the following optical properties :—
>
> $$2Vx = \pm\ 15^\circ;\ ny, nz = 1{\cdot}579 \pm {\cdot}003.$$
>
> "Material mixed with apatite and pyroxene from the Mamba Pit appears to have good exfoliation properties but it contains minute rounded blades of a hard mineral, probably pyroxene, which may be detrimental. Judging from its properties and composition it is nearer true mica than any of the other vermiculite examined. It is darker in colour and has the following optical properties :—
>
> $$2Vx = \text{near } 0^\circ;\ ny, nz = 1{\cdot}592 \pm {\cdot}003."$$
>
> "The vermiculite from the dump one mile N.N.E. of Loole Kop varies considerably from the others, and does not exfoliate as well. It is golden-brown in colour instead of dark-brown or blackish and less flexible. From a cursory spectroscopic examination the base-content also seems to be less than that of the other samples submitted. It seems to represent a further stage in the alteration from original mica. It is probable that this is a feature of weathering and, if this is correct, this locality might very well produce pure enough material for exploitation. The physical properties and composition are rather different from the other vermiculites, both the axial angles and the refractive indices being lower. The optical properites $2Vx = \pm\ 0^\circ$ and $ny, nz = 1{\cdot}534 \pm {\cdot}003$ seem to be approaching those of saponites."

This latterly described material from 1 mile N.N.E. of Loole Kop represents weathered vermiculite from a dump. The Minerals Research Laboratory tested three samples (Nos. 5, 6 and 7 on page 23) from the same locality but from different pits which have recently been opened up. Hence their material was comparatively fresh and not subjected to weathering for any length of time. Partridge's prediction proved correct as all the material tested by the Minerals Research Laboratory expanded well, yielding silvery white products.

The Mamba Pit ore tested by Partridge occurs intimately associated with apatite in varying amounts and comes from a depth of about twelve feet. The specimen tested from Valentine's Beryl Pit comes from a depth of about 30 feet, and the Minerals Research Laboratory reports it to expand fairly well.

The Minerals Research Laboratory investigated seven samples subsequent to the tests carried out in the Geological Survey Laboratory. The samples were taken at random from different parts of the area*. Only two samples were of poor quality. According to field evidence the two poor samples, however, only represent a very small proportion of the exposed vermiculite at those two sites. Most of the material expands well according to cursory tests carried out in the field.

* The results of the investigations carried out at the Minerals Research Laboratory, Johannesburg, are contained in the Appendix.

Much of the vermiculite ore in this area carries apatite, pyroxene, and near the surface also calcrete. Although some of the ore is very pure the workability of the vermiculite as a whole will depend larg ly on whether the vermiculite can be economically recovered in a marketable form. It would in most cases be impossible to separate the finely divided apatite and pyroxene and also the interlaminated calcrete from the vermiculite by a manual process. The calcrete could be dissolved out by a dilute acid, and a suitable mechanical process could probably be found to separate the flaky vermiculite from the granular apatite and pyroxene.

Judging from the tests carried out in the Geological Survey and the Minerals Research Laboratory it seems as if most of the vermiculite in this area is of good quality for the purpose where strong exfoliation is a necessary requirement. It is, however, advisable to have more tests made of material from different localities before attempts are made to work the deposit for vermiculite.

(*b*) Available Quantities.

As is the case in most lenticular and irregular pockety deposits it is very difficult, if not altogether impossible, to estimate the available ore reserves. The limited amount of exploratory work, the irregularly spaced workings, together with the comparatively large area covered by a calcrete overburden add to the uncertainty of such an estimate. The possibility that further deposits of vermiculite may be found is unquestionable. In an estimate the possible presence of such hidden bodies should not be disregarded.

It has been stated that very little exploration has been done on the vermiculite and that the opening up of this mineral in various parts over the pyroxenite area is to be attributed to its intimate association with the apatite deposits. An attempt will be made to show the quantities of vermiculite exposed in the various workings.

At Valentine's Beryl Pit about 50 tons of weathered vermiculite are lying at grass. Abundant vermiculite is exposed in the pit and numerous pits in the immediate vicinity bear vermiculite in appreciable quantities.

The Mamba Pit is situated wholly in a mass of vermiculite intimately admixed with pyroxene and apatite. Pits around this working exhibit a similar mineral association. The total quantities of vermiculite in and around this working must be large.

About one mile N.N.E. of Loole Kop various pits exposed massive flaky vermiculite. A few hundred tons have been extracted but, judging from the amounts still remaining in the pits together with unexposed deposits which are indicated on the surface by vermiculite protruding from the soil and the calcrete overburden, the available ore reserves probably very greatly exceed the mined material.

On the farm Wegsteek No. 494 about 300 tons of vermiculite are lying at grass and abundant vermiculite is exposed in numerous old workings.

Very large quantities of vermiculite are exhibited in the numerous isolated pits situated about one mile S.S.E. of the beacon on Loole Kop. Some workings show large massive flakes while others again display small vermiculite flakes intimately admixed with granular apatite and pyroxene. In a few cases large clean flakes form pockets in the finely divided vermiculite-apatite-pyroxene deposits.

Rough estimates of quantities of vermiculite extracted from the individual workings can be given. The total amount of vermiculite in the pyroxenite area, however, greatly exceeds the quantities which have been extracted from the pits and exposed during apatite mining, and it is reasonable to state that the available ore reserves must be considerable.

(*c*) Transport.

The nearest railhead is Mica Siding which is situated some 25 miles by road to the south-west of the mining area. The road would need repair before heavy transport could be used.

The drifts across the Selati and Sudimone rivers are especially bad and a concrete causeway over these rivers would have to be built.

Mica Siding is 201 miles from Lourenço Marques which is the nearest harbour.

(*d*) Water.

South African Phosphates, Ltd., erected pumping stations at the Selati and Olifants rivers. If the water of the Selati river dries out during drought-stricken seasons then the supply is obtained from the Olifants river which maintains a constant flow throughout the driest seasons. The nearest pump is on the Selati river about three quarter mile away, while the pumping station on the Olifants river is situated some four miles from the abandoned phosphate plant.

Water occurs in minor quantities in a borehole on the farm Schiettocht and in wells along some of the rivers, but these are merely adequate to supply local domestic demands.

(*e*) Labour.

Situated in the immediate vicinity of the mining area is the Makushane Location whence native labour should easily be obtainable.

Numerous other " kraals " occur in the Lowveld region of this area and should supply adequate labour if required. At Thabina, some fifty miles to the east of Loole Kop, a dense native population lives.

(*f*) Fuel.

Although these deposits are situated in a densely vegetated area suitable wood for firing of a plant is very scarce indeed. The nearest coal mine from which coal could be obtained near Breyten is situated some 337 miles by rail from Mica Siding.

For domestic purposes abundant wood is obtainable.

(*g*) The Uses of Vermiculite.

The vermiculite is refined and subsequently prepared by roasting to cause exfoliation. The final product is used for various purposes, the most important of which are detailed below :—

> Insulating material for steam pipes, refrigerating equipment, insulating bricks, wall-board, etc.
>
> It may be used as an aggregate in magnesium oxychloride cement products, as a light-weight, fireproof subsitute for cork in all types of heat and sound insulation, etc.

For more detailed information regarding the uses of this material see also the Appendix at the end of this bulletin.

VI.—ON THE TRACING OF VERMICULITE DEPOSITS.

First of all it is to be remembered that all the hitherto exposed deposits of any size are confined to the pyroxenite area which, as has been stated before carries, besides pyroxenite, serpentinous and actinolitic rocks. This pyroxenite area is everywhere covered by a thick overburden of calcrete or by a brownish soil. In only a few instances does the pyroxenite crop out on the surface. It is only reasonable to maintain that other vermiculite deposits exist which are hidden by the calcrete and soil. The irregular pockety nature of the individual deposits also suggests that it is more than likely that vermiculite deposits, which are not exposed by weathering at all, occur in the country rock. Such deposits would naturally not be indicated on the present surface nor in the calcrete overburden.

It will prove both difficult and expensive to prospect for such deposits on geological grounds, but geophysical prospecting may possibly reveal such hidden bodies. It is contemplated by the Geological Survey to have a few preliminary tests carried out in the laboratory, and if these tests prove encouraging the application of geophysical investigations on these deposits will be attempted in the field.

In searching for vermiculite deposits the prospector is strongly advised to pay special attention to outcrops of serpentinous rocks. Hitherto appreciable deposits have everywhere been found in or near such outcrops. Theoretically one would also expect the serpentinous rocks to carry more "vermiculite" on account of the larger quantities of available magnesium contained in these rocks compared with the pyroxenites.

It is to be noted that no vermiculite nor apatite has hitherto been found in the serpentinous rocks largely covered by calcrete on the farm Rhoda No. 219, situated just over three miles due south of Loole Kop. Careful and systematic prospecting may also reveal vermiculite in this rock.

Vermiculite has been found in the calcrete above deposits of this area but it is not preserved to the same extent as the apatite and is usually very difficult to find. In the soil overburden, however, vermiculite seems to be preserved much longer than in the calcrete. The golden-yellow to bronzy flakes show up brightly in the otherwise dull soil. Such phenomena have frequently been observed in the vicinity of the deposits. Here it is to be remembered that vermiculite is easily transported by water, and such flakes should be traced to the most likely site of origin before prospecting is started.

In one case, about one mile N.N.E. of Loole Kop on the farm Loole No. 199, vermiculite was indicated on the surface by large flakes protruding from the soil. These were found to be in the same position in which they were originally situated in the deposit.

VII.—CONCLUSIONS.

Vermiculite has received very little attention in the past by prospectors. All the workings are too small to express any definite opinion. Judging however from the numerous pits in which vermiculite occurs, either alone or closely associated with apatite, the available quantities thereof seem to exceed that of apatite. Individual bodies of the former are usually of greater size than the latter, but, owing to the irregular nature of the deposits and the

lack of exploratory work, not even an attempt to estimate accurate quantities could be made. The extensive overburden of calcrete and soil would enhance the inaccuracy of any such estimate. It is however reasonable to state that the quantities of this material must be considerable.

The mode of occurrence of vermiculite is seemingly very similar to that of apatite. Small deposits of vermiculite intimately associated with apatite and also deposits of vermiculite alone have been proved to be of a discontinuous nature both in the vertical and lateral plane. The larger deposits have not been prospected to such depths as to warrant the expression of a definite opinion, but it is most probable that similar irregularities will be displayed, but on a much larger scale.

The origin of vermiculite is rather uncertain. It may either have been formed by a weathering process, or by a hydrothermal alteration which leached out some of the potash of the mica, which probably originally was phlogopitic. If vermiculite is of hydrothermal origin then it may be expected to continue to great depths. Should it however be a weathering product of phlogopitic mica, then a depth limit will be reached where the vermiculite will pass over to true mica which may be of no commercial value and certainly of no use for the purpose for which vermiculite is applied. The deepest working on a vermiculite-rich deposit hitherto opened up is more or less 30 feet at Valentine's Beryl Pit. The vermiculite from the deepest point proved to be of fair quality.

It is relevant to mention that typical flexible phlogopitic mica of a dark brown colour has been found in close association with vermiculite in several closely-spaced pits S.S.E. of Loole Kop. The pits are not more than twelve feet deep. North of Loole Kop golden-yellow vermiculite flakes have been found with a core of dark brown flexible mica. The inner core exfoliates much less than the outer rim of vermiculite which is of good quality. This type of material comes from a depth of about ten feet. These facts are not sufficient to prove that vermiculite is a weathered product. Such alterations may have been brought about by hydrothermal solutions acting upon mica. Only subsequent mining will prove the depth to which vermiculite extends.

Most of the material tested by the Geological Survey Laboratory and the Minerals Research Laboratory expands well and is therefore of value. The tests also show that a fair amount of selection will have to be done to obtain marketable vermiculite. It is advisable to carry out tests during mining to avoid the expense of extracting inferior material. Much of the vermiculite is pure but much of it contains calcrete, pyroxene and apatite as impurities. Such material could perhaps be cleaned by mechanical processes and also by acid to dissolve out the calcrete. In depth the calcrete which is so frequently contaminated with the ore should become an insignificant factor or be altogether absent.

If the vermiculite of Palaboroa persists in depth as well as laterally in the form of marketable material then there is every reason to believe that vermiculite can be extracted in commercial quantities from this occurrence.

The United States of America and Russia* are at present the chief producers of vermiculite. The economic exploitation of the Palaboroa deposits will thus also depend on whether its vermiculite can be marketed at a price to compete with the overseas product.

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* Annual Report of the Imperial Institute, 1937, page 41.

VIII.—APPENDIX.

Vermiculite from Palaboroa.

by

J. E. LASCHINGER.

Vermiculite is a hydrated mineral derived from certain micas. Its commercial importance depends upon its property of exfoliating, on rapid heating, by the loss of its combined water. The resulting accordion-like granular material is very low in apparent specific gravity. Because of its low thermal conductivity, its comparatively high refractoriness at elevated temperatures, and its freedom from liability to deterioration it forms a useful material for thermal and acoustic insulation. It has also been used as an aggregate in making light plasters and boards. The expanded material is sub-metallic lustrous silver to gold-brown in colour ; hence fine material can be used as a pigment in inks and paints.

The methods employed in the United States for the preparation of the material are simple, as the following summary will show.

The vermiculite is easily mined with pick and shovel, little blasting being needed. The material is passed over screens to eliminate the fines, which are discarded. The product is then dried, broken by means of a hammer-mill and screened to various sizes.

The dried, sized vermiculite is ready for "expanding." Plant for this purpose appears to vary widely in design. In all processes the material must be subjected to a temperature of about 900°–1000°C. for a few seconds, and then be allowed to cool as rapidly as possible.

Any sand, stone, or dirt in the raw material is eliminated in the course of treatment, for the most part in the pneumatic conveyors used in handling the expanded product.

Palaboroa samples.—The seven samples received were designated as follows :—

No. 1. Mamba Pit.
No. 2. Valentine's Beryl Pit.
No. 3. East of No. 1 Working.
No. 4. North of Valentine's Beryl Pit.
No. 5. 50 yds. north of L.P. 2150.
About $1\frac{1}{2}$ miles N.N.E. of Loole Kop.
No. 6. 80 yds. north of L.P. 2138.
Just over 1 mile N.N.E. of Loole Kop.
No. 7. From Mr. Cleveland. 10′ below surface.
About 1 mile N.N.E. of Loole Kop.

The tests made in the laboratory were selected in order to compare the quality of the Palaboroa samples with that of the vermiculite in commercial use in the United States.

Portions of each sample were dried and broken in a small disintegrator, and screened to the following sizes :—

$-\frac{3}{4}'' + \frac{1}{2}''$.
$-\frac{1}{2}'' + \frac{1}{4}''$.
$-\frac{1}{4}'' +$ 28 B.S.
$-$ 28 B.S.

The portions of each sample obtained were expanded in a hot muffle (980°C.), cooled rapidly, and reserved for examination. Table 1 (page 26) presents the results of these examinations which were :—

(1) Density of packing, under pressure of 30 lbs./sq. ft.

(2) Thermal conductivity of the material when packed in a layer 3 cm. thick and under a pressure of 30 lbs./sq. ft. applied by means of a flat weight. These measurements were made by the method of Van Dusen (Jour. Am. Soc. Heat. Vent. Eng. 26,625 [1920]) and the values for other substances and the American vermiculite included for comparison were made by the same method.

(3) The behaviour at elevated temperatures in a neutral atmosphere. Two temperatures are quoted, the "sintering" and "melting" temperatures.

As the material is heated to increasing temperature, no sensible permanent changes occur until a certain point is reached at which, it appears, some constituent present in minor proportion fuses. The material, when cooled from this temperature, is seen to have shrunk and become brittle. If the temperature is further increased a point is reached at which the material collapses abruptly and fuses to a slag.

Table 2 (page 27) presents the chemical analyses of three samples : No. 7 which is of good quality ; No. 2 which is of a fair quality ; and No. 4 which is of poor quality. These analyses are based on the air-dried samples before expansion. It will be seen that, with the exception of the free and combined moisture content, the analyses reflect little of the difference in quality of the samples.

General Description of Samples.

No. 1. Massive, black, friable. Mica crystals small and intergrown, with haphazard orientation, with small included crystals of apatite.

The material breaks down to grains dominantly of — $\frac{1}{4}''$ + 30 size. Expands well, yielding a material of black metallic lustre, but considerably contaminated with sandy apatite grains which are, however, easily removable by air classification.

No. 2. White colour, friable transverse to cleavage planes. Contains some lenses of infiltrated banded chalcedony. Expands fairly well, yielding material of good silver-white to faintly brown colour.

No. 3. Dark brown colour, elastic transverse to cleavage planes, difficult to break down. Expands poorly, giving large proportion of unaltered plates of mica.

No. 4. Dark brown to black, practically unaltered mica. Almost unaffected by heat, broken material light, but packs badly.

No. 5. Light brown to golden colour, friable transverse to cleavage planes Expands well, yielding a light product of silvery-white colour.

No. 6. Similar to No. 5.

No. 7. White to light lustrous brown. Expands well, yielding white to silvery products.

The results obtained indicate that Palaboroa vermiculite of the quality of samples Nos. 2, 5, 6 and 7 is closely comparable to American vermiculite.

Value and Uses of Vermiculite.

Expanded vermiculite is used in the United States for thermal insulation for all temperatures. Its thermal conductivity is higher than that of granulated cork, but its lighter weight, freedom from liability to rot or develop mould, and non-inflammability make it more desirable for many purposes. It is used for the insulation of refrigeratory chambers, motor-car bodies, domestic refrigerators and for numerous similar purposes. The two largest outlets appear to be in the insulation of houses, where a layer of grains is laid on ceilings or held by cloth, wirescreen or spread-metal bratticing under the roof tiles or sheeting, and for the thermal insulation of large furnaces, where it is laid on the roof and applied to the walls, being held in place by an outer shell of bricks made of expanded vermiculite bonded in clay.

Vermiculite plasters composed of expanded material mixed with Portland cement, Keene's cement or plaster of Paris as a binder have been used for acoustic purposes.

The greatest specific advantage possessed by vermiculite above other materials lies in the possibility of transporting the material in the unexpanded condition. In the expanded form, vermiculite weighs from 6 to 14 lbs. per cubic foot, but in its natural state it can be packed to a density varying from 50 to 90 lbs. per cubic foot. Since the apparatus for expansion may be conveniently erected or situated anywhere, considerable savings in carriage cost may be realised.

No dependable figures can be obtained for the prices obtainable for the products. In the United States the price varies over an extremely wide range, depending on the location of the consumer with respect to the sources of supply of vermiculite and competing products. The value at one mine in Carolina is given as 7 dollars per ton, and the price paid by consumers on an average appears to be about 15 dollars per ton. The range in price at various places is from 10 to 75 dollars per ton. The valuation of Palaboroa vermiculite is therefore a matter of commercial enquiry, while the market in which it will be politic to seek an outlet must also be investigated.

TABLE 1.—EXPANDED VERMICULITE.

Sample No.	Size.	lbs. per cu. ft.	$K_1 \times 10^4$	K_2	Temperature °C.		Texture after expanding.
					Sinter.	Melt.	
1	+½"	—	—	—	—	—	—
1	−½" +¼"	—	—	—	—	—	—
1	−¼" +28	11·9	1·74	0·51	1230	1280	Brittle.
1	−28	13·9	—	—	—	—	Brittle.
2	+½"	3·7	1·43	0·42	1240	1350	Tough.
2	−½" +¼"	4·1	1·46	0·42	1240	1350	Tough.
2	−¼" +28	7·1	1·55	0·45	1240	1350	Tough.
2	−28	14·1	1·60	0·46	1240	1350	Tough.
3	+½"	9·9	—	—	—	—	Platy.
3	−½" +¼"	9·9	—	—	—	—	Platy.
3	−¼" +28	14·1	—	—	—	—	Platy.
3	−28	35·3	—	—	—	—	Platy.
4	+½"	8·5	—	—	—	—	Platy.
4	−½" +¼"	8·5	—	—	—	—	Platy.
4	−¼" +28	9·9	—	—	—	—	Platy.
4	−28	16·7	—	—	—	—	Platy.
5	+½"	5·0	1·60	0·46	1230	1350	Brittle.
5	−½" +¼"	5·0	1·65	0·48	1230	1350	Brittle.
5	−¾" +28	8·1	1·65	0·48	1230	1350	Brittle.
5	−28	14·8	1·77	0·51	1230	1350	Brittle.
6	+½"	3·5	1·48	0·43	1230	1350	Brittle.
6	−½" +¼"	3·8	1·53	0·44	1230	1350	Brittle.
6	−¼" +28	6·2	1·48	0·43	1230	1350	Brittle.
6	−28	11·7	1·63	0·47	1230	1350	Brittle.
7	+½"	4·1	1·50	0·43	1280	1350	Brittle.
7	−½" +¼"	4·1	1·55	0·45	1280	1350	Brittle.
7	−¼" +28	6·1	1·50	0·44	1280	1350	Brittle.
7	−28	10·6	1·65	0·48	1280	1350	Brittle.
American Vermiculite	−½" +¼"	4·5–6·5	1·58 (At 300°F.)	0·46	—	1350	(1)
	−¼" +10	5·8–7					
	−10 +28	6·8–8	—	—	—	—	—
	−28	10–14	—	—	—	—	—
Regranulated Cork	$^3/_{16}$"	9·4	1·02	0·30	—	—	(2)
Cork Board	....	9·9	1·04	0·30	—	—	(2)
85% Magnesia	....	19·0	1·75	0·50	—	—	(2)
Asbestos Millboard	....	61·0	2·90	0·83	—	—	(2)

(1) Steele, Trans. A.I.M.E., 109 (1934).

(2) Van Dusen, Jour. Am. Soc. Heat. Vent. Eng. 26 : 646 (1920).

K_1 Thermal conductivity. Cals./sq.cm./sec./°C./cm.

K_2 Thermal conductivity. B.T.U./sq.ft./hr./°F./inch.

TABLE 2.—ANALYSES OF VERMICULITE.

Sample. Number.	7. North of Loole Kop. (Good).	2. Valentine's Beryl Pit. (Fair).	4. North of Valentine's Beryl Pit. (Poor).
	%	%	%
SiO_2	39·37	44·32	41·21
TiO_2	1·25	1·32	1·60
Al_2O_3	12·08	6·63	8·06
Fe_2O_3	5·45	7·65	5·68
FeO	1·17	2·05	3·52
MnO	0·30	1·01	0·61
MgO	23·37	21·92	24·97
CaO	1·46	3·22	2·10
Na_2O	0·80	0·74	1·30
K_2O	2·46	2·30	6·96
H_2O + 105° (Combined Water).	5·18	3·37	1·52
H_2O — 105° (Moisture).	6·02	3·28	1·70
P_2O_5	0·15	0·81	0·03
CO_2	0·60	1·17	0·61
Li_2O	0·03	Trace.	0·01
ZrO_2	Nil.	Nil.	Nil.
Cr_2O_3	Nil.	Nil.	Nil.
V_2O_3	Nil.	Nil.	Nil.
NiO	Nil.	Nil.	Nil.
CoO	Nil.	Nil.	Nil.
BaO	0·03	0·03	0·02
Cl	0·02	0·02	0·02
F	Nil.	Nil.	Nil.
SO_3	0·02	0·08	0·02
S	0·18	0·43	0·10
	99·94	100·35	100·04
Oxygen equivalent to Cl	—	—	—
Oxygen equivalent to S in pyrite	0·08	0·16	0·04
Corrected TOTAL	99·86	100·19	100·00

ANALYST: L. W. VERMEULEN.